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(54) **AUTOMATIC BANDWIDTH ADJUSTMENT ON MULTI-FIBER OPTICS**

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(51) **Int. Cl.**

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H04B 10/00	(2013.01)
H04B 10/08	(2006.01)
H04B 17/00	(2015.01)
H04B 10/03	(2013.01)

(52) **U.S. Cl.**
CPC ***H04B 10/03*** (2013.01)

(58) **Field of Classification Search**
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USPC 398/2, 5, 10, 13, 17, 27, 33, 38
See application file for complete search history.

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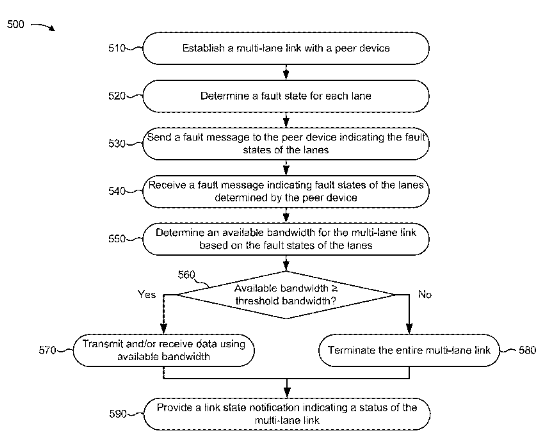
(57) **ABSTRACT**

A device is configured to store information indicating a threshold bandwidth with which a multi-lane link is permitted to operate. The device may establish the multi-lane link with a peer device. The multi-lane link may include multiple lanes used to communicate data with the peer device. The device may determine fault states for the lanes included in the multi-lane link. A fault state, for a particular lane, may indicate that the particular lane is faulty. The device may determine an available bandwidth for the multi-lane link based on the fault states for the lanes. The device may selectively terminate the multi-lane link or operate the multi-lane link at the available bandwidth based on whether the available bandwidth satisfies the threshold bandwidth.

20 Claims, 8 Drawing Sheets



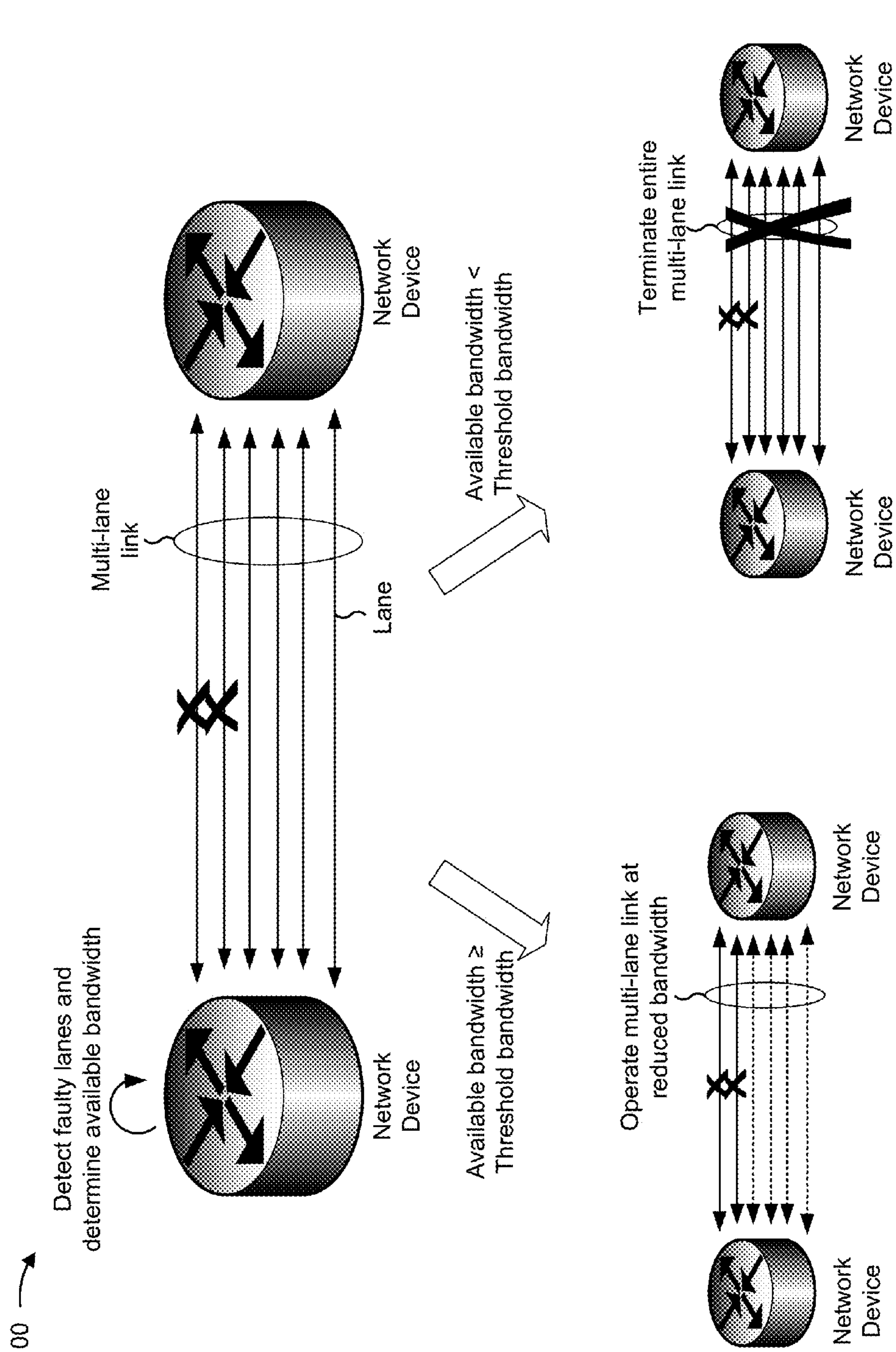
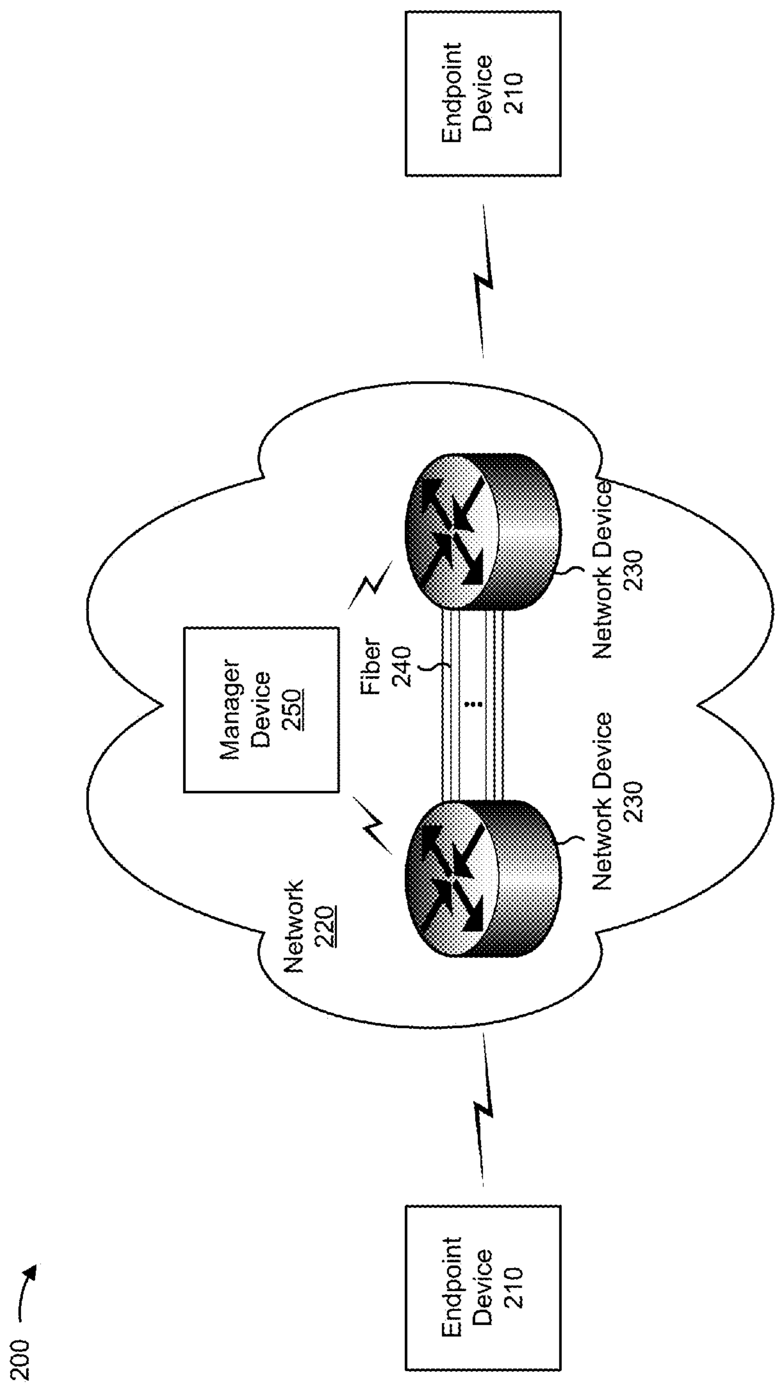

100
Detect faulty lanes and determine available bandwidth
Network Device
Multi-lane link
Lane
Network Device
Available bandwidth ≥ Threshold bandwidth
Available bandwidth < Threshold bandwidth
Operate multi-lane link at reduced bandwidth
Network Device
Network Device
Terminate entire multi-lane link
Network Device
Network Device

FIG. 1



Endpoint Device 210
Network 220
Manager Device 250
Fiber 240
Network Device 230
Network Device 230
Endpoint Device 210
200

FIG. 2

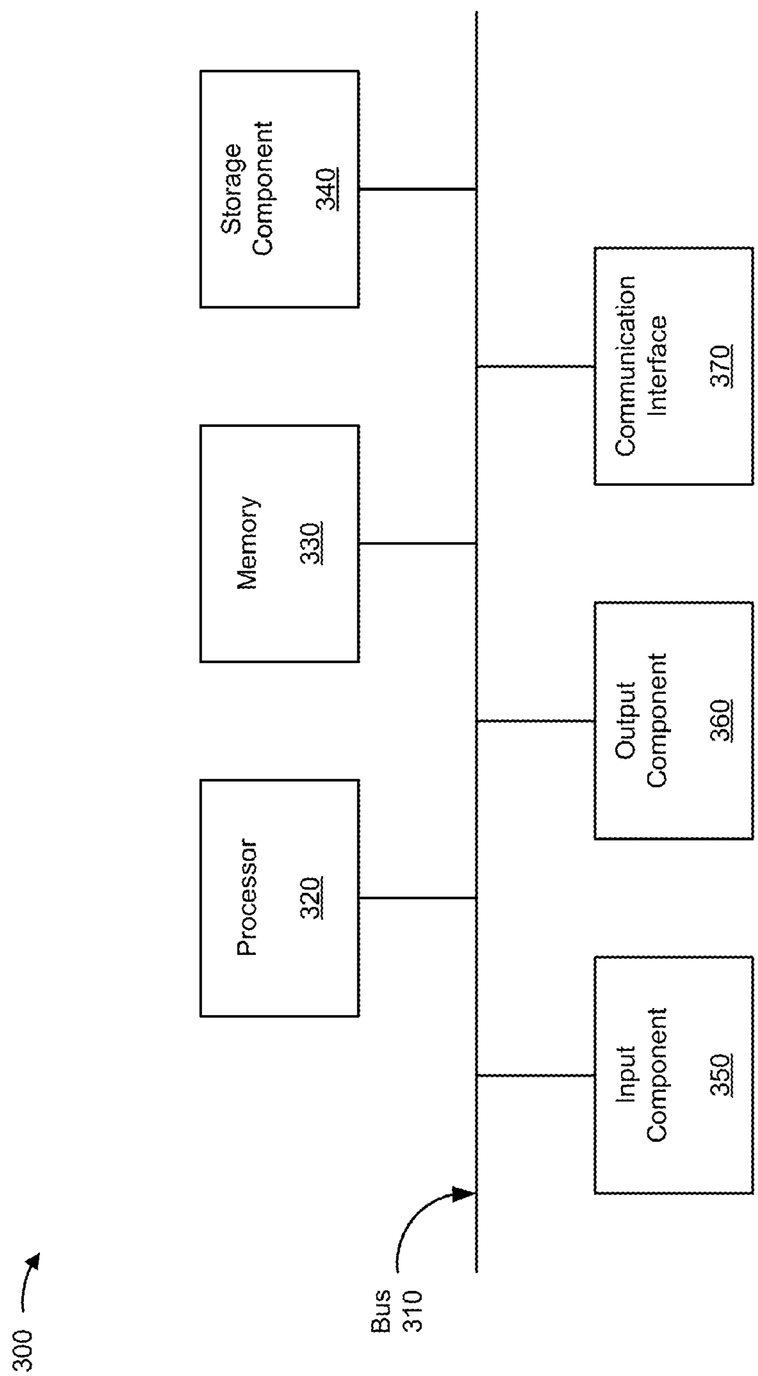

300
Bus 310
Processor 320
Memory 330
Storage Component 340
Input Component 350
Output Component 360
Communication Interface 370

FIG. 3

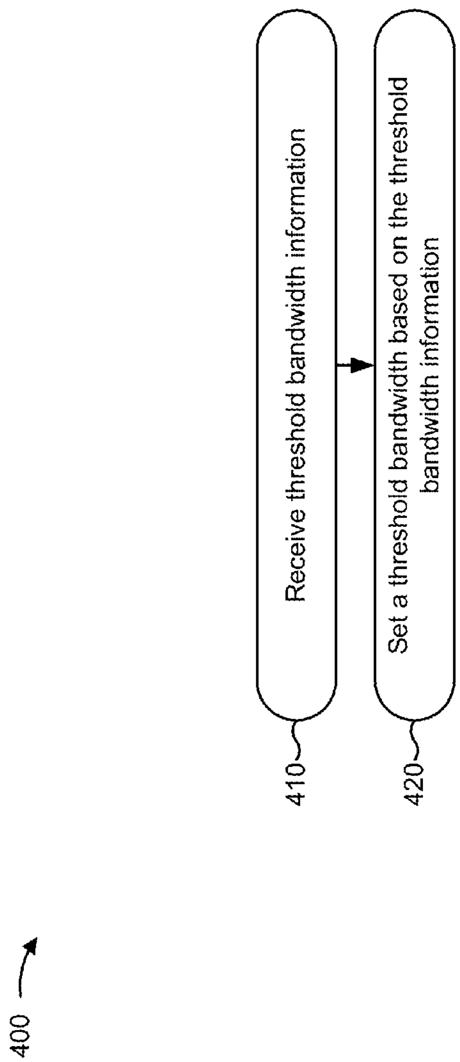

400
410
Receive threshold bandwidth information
420
Set a threshold bandwidth based on the threshold bandwidth information

FIG. 4

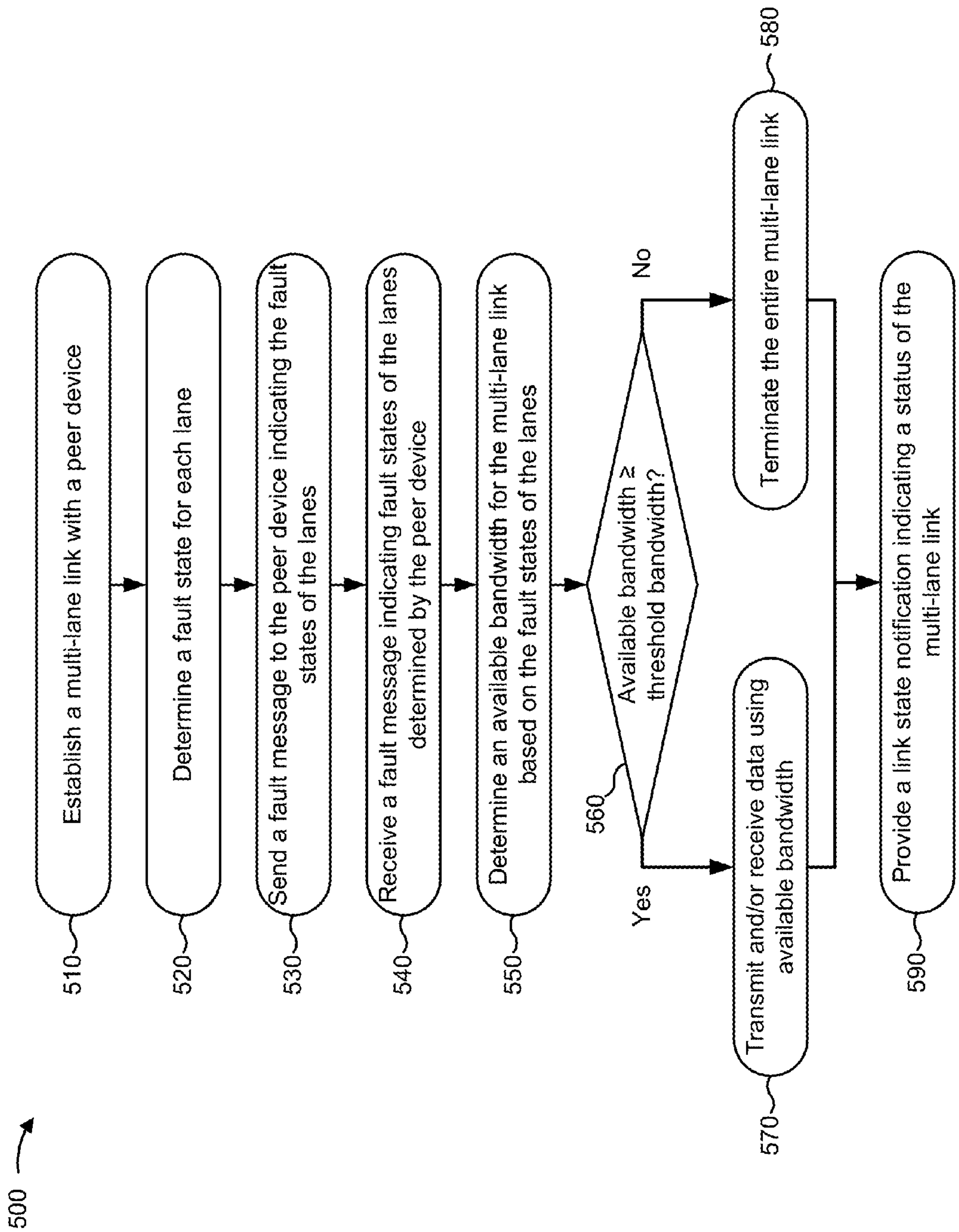

500
510
Establish a multi-lane link with a peer device
520
Determine a fault state for each lane
530
Send a fault message to the peer device indicating the fault states of the lanes
540
Receive a fault message indicating fault states of the lanes determined by the peer device
550
Determine an available bandwidth for the multi-lane link based on the fault states of the lanes
560
Available bandwidth ≥ threshold bandwidth?
Yes
No
570
Transmit and/or receive data using available bandwidth
580
Terminate the entire multi-lane link
590
Provide a link state notification indicating a status of the multi-lane link

FIG. 5

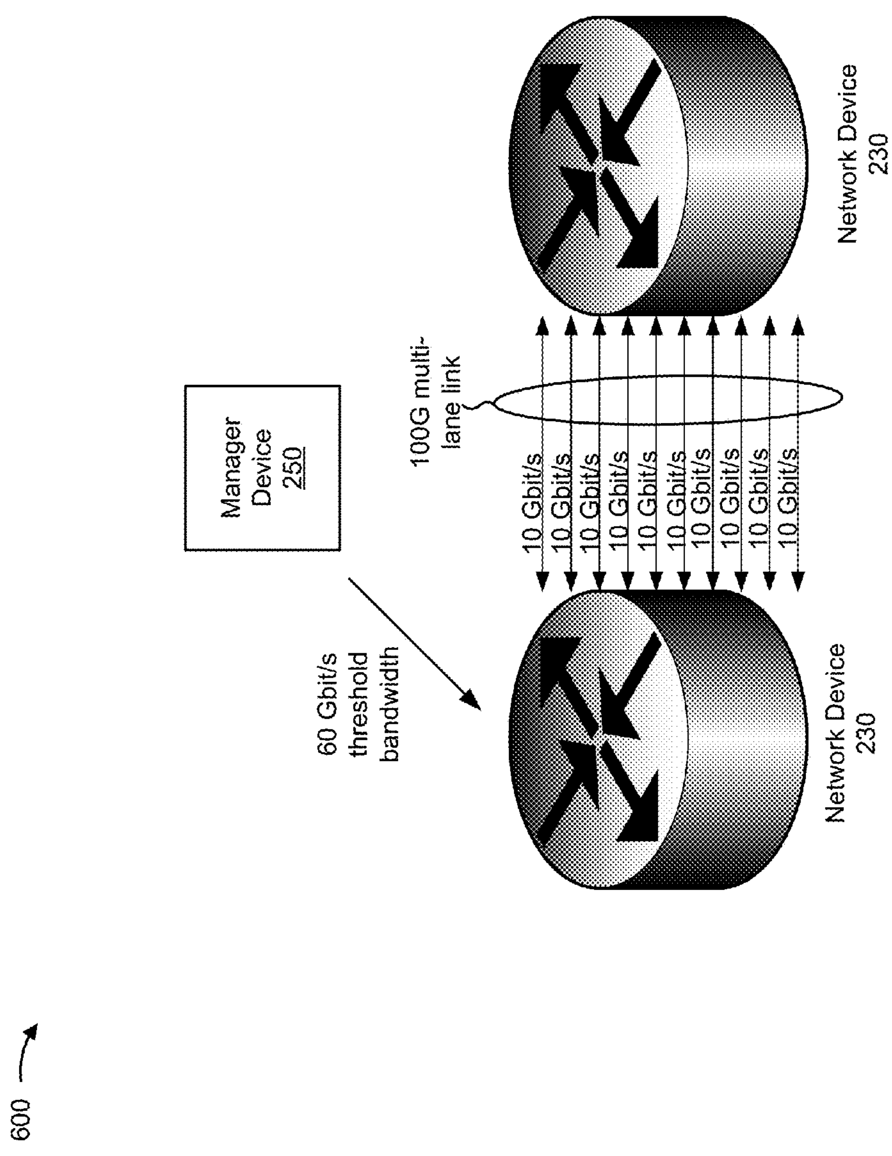

600
Manager Device 250
60 Gbit/s threshold bandwidth
100G multi-lane link
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
Network Device 230
Network Device 230

FIG. 6A

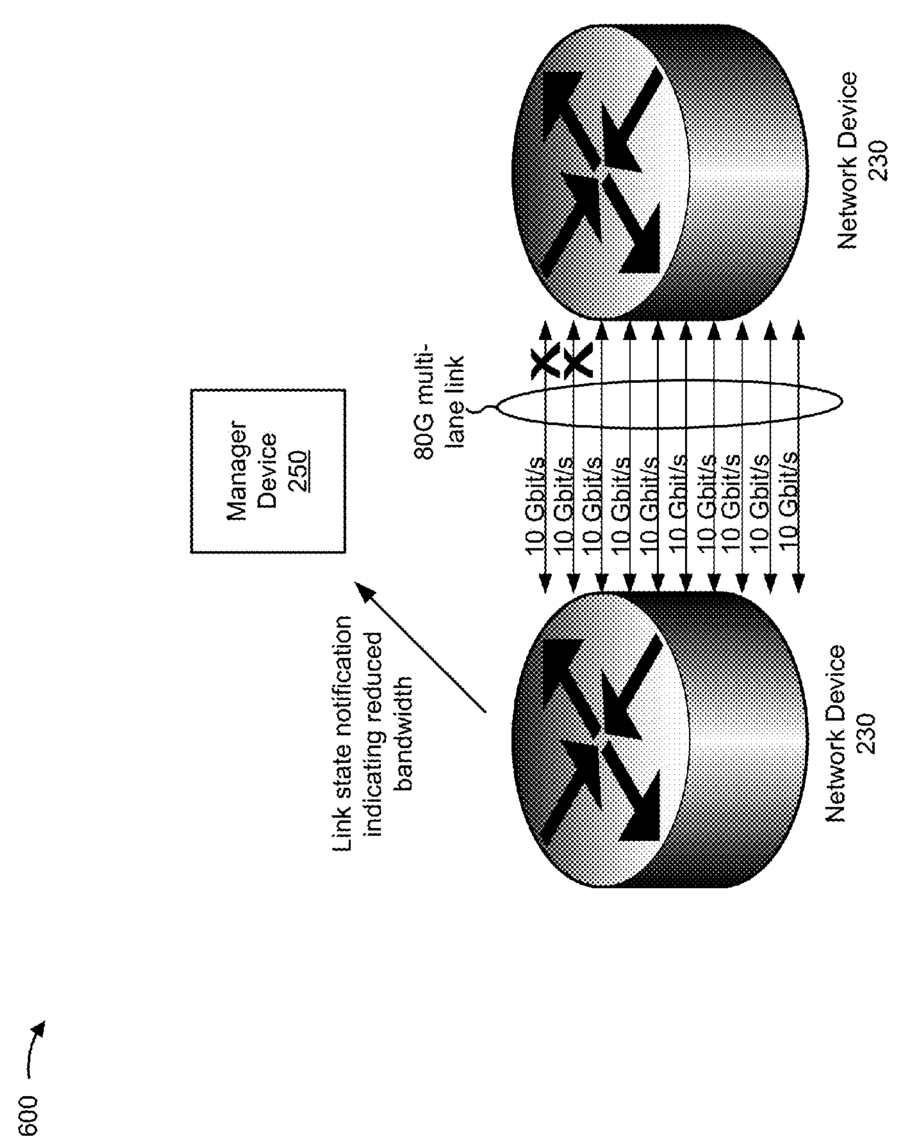

600
Manager Device 250
Link state notification indicating reduced bandwidth
80G multi-lane link
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
Network Device 230
Network Device 230

FIG. 6B

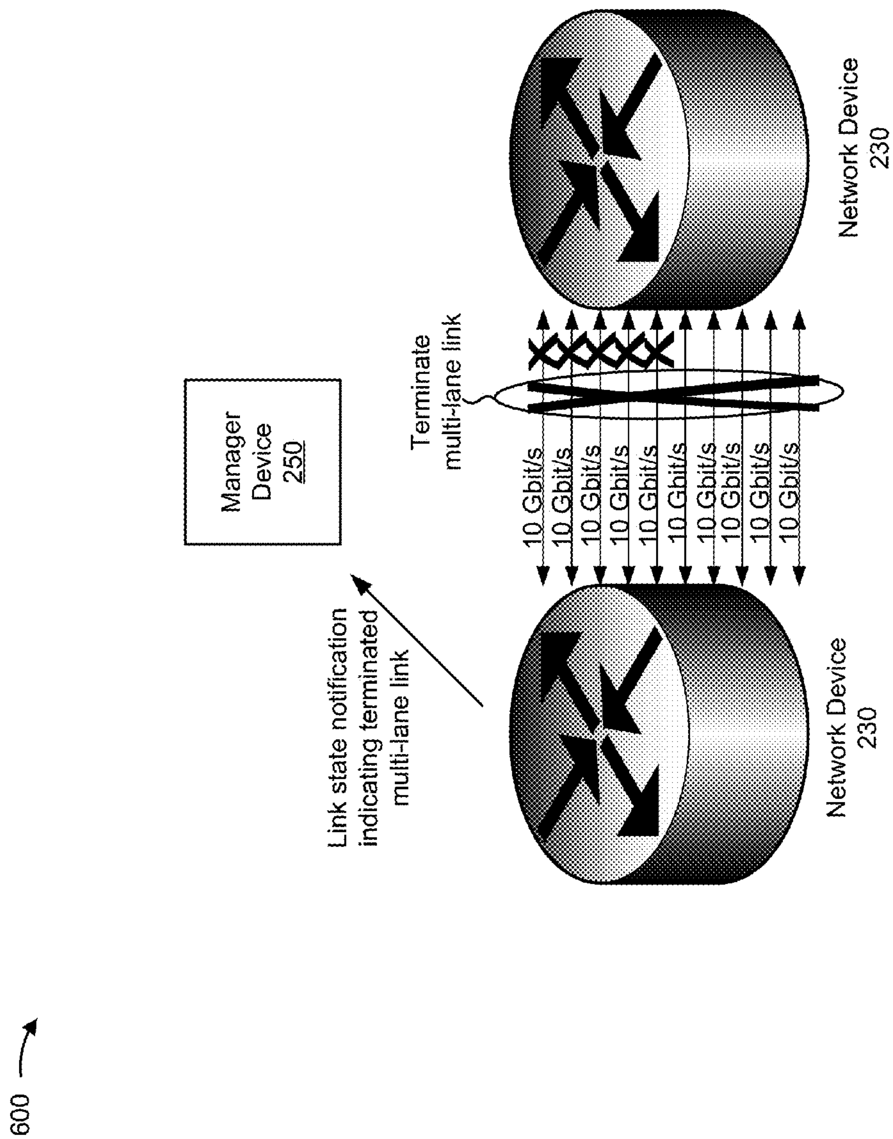

600
Manager Device 250
Terminate multi-lane link
Link state notification indicating terminated multi-lane link
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
10 Gbit/s
Network Device 230
Network Device 230

FIG. 6C

AUTOMATIC BANDWIDTH ADJUSTMENT ON MULTI-FIBER OPTICS

BACKGROUND

A transmitter may transmit data over a multi-lane link by distributing the data over multiple lanes, which each have a particular bandwidth. The data may be reassembled at a receiver such that an effective bandwidth of the multi-lane link is equal to the sum of the bandwidth of each lane. For example, 100 gigabit (100G) Ethernet may use ten lanes each having a bandwidth of 10 gigabit per second (Gbit/s). However, if one of the lanes is faulty, the data may not properly be reassembled by the receiver, and the entire multi-lane link may be silently terminated without notification even if healthy lanes still exist.

SUMMARY

According to some possible implementations, a device may store information indicating a threshold bandwidth with which a multi-lane link is permitted to operate. The device may establish the multi-lane link with a peer device. The multi-lane link may include multiple lanes used to communicate data with the peer device. The device may determine fault states for the lanes included in the multi-lane link. A fault state, for a particular lane, may indicate that the particular lane is faulty. The device may determine an available bandwidth for the multi-lane link based on the fault states for the lanes. The device may selectively terminate the multi-lane link or operate the multi-lane link at the available bandwidth based on whether the available bandwidth satisfies the threshold bandwidth.

According to some possible implementations, a computer-readable medium may store instructions, that when executed by a processor, may cause the processor to establish a multi-lane link with a peer device. The multi-lane link may include a plurality of lanes used to communicate data with the peer device. The instructions may cause the processor to determine fault states for the plurality of lanes included in the multi-lane link. At least one of the fault states may indicate a particular lane, of the plurality of lanes, is faulty. The instructions may cause the processor to determine an available bandwidth for the multi-lane link based on the fault states for the plurality of lanes. The instructions may cause the processor to selectively terminate the multi-lane link based on whether the available bandwidth satisfies a threshold bandwidth. The threshold bandwidth may indicate a minimum bandwidth with which the multi-lane link is permitted to operate.

According to some possible implementations, a method may include establishing, by a device, a multi-lane link with a peer device. The multi-lane link may include a plurality of lanes used to communicate data with the peer device. The method may include determining, by the device, fault states for the plurality of lanes included in the multi-lane link. At least one of the fault states may indicate a particular lane, of the plurality of lanes, is faulty. The method may including determining, by the device, an available bandwidth for the multi-lane link based on the fault states for the plurality of lanes. The method may include selectively operating, by the device, the multi-lane link at the available bandwidth based on whether the available bandwidth satisfies a threshold bandwidth. The threshold bandwidth may indicate a bandwidth with which the multi-lane link is permitted to operate.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram of an overview of an example implementation described herein;

FIG. **2** is a diagram of an example environment in which systems and/or methods, described herein, may be implemented;

FIG. **3** is a diagram of example components of one or more devices of FIG. **2**;

FIG. **4** is a flow chart of an example process for setting a threshold bandwidth;

FIG. **5** is a flow chart of an example process for automatically adjusting a bandwidth on a multi-lane link; and

FIGS. **6**A-**6**C are diagrams of an example implementation relating to the example processes shown in FIGS. **4** and **5**.

DETAILED DESCRIPTION

The following detailed description of example implementations refers to the accompanying drawings. The same reference numbers in different drawings may identify the same or similar elements.

A maximum possible bandwidth of a multi-lane link may not always be needed to properly communicate data. Rather, a lower threshold bandwidth may be satisfactory to properly communicate the data. Accordingly, if one or more lanes in a multi-lane link become faulty, the multi-lane link may still be used at a reduced bandwidth by distributing the data to healthy lanes. However, if the reduced bandwidth falls below the threshold bandwidth, the multi-lane link may become unsatisfactory for communicating the data, and the entire multi-lane link may be terminated.

Implementations described herein may allow a multi-lane link to operate at a reduced bandwidth when lanes become faulty. However, in some implementations, the multi-lane link may be terminated if an available bandwidth fails to satisfy a threshold bandwidth, thus ensuring the multi-lane link operates at a satisfactory bandwidth. Accordingly, service outages may be minimized while maintaining a satisfactory bandwidth.

FIG. **1** is a diagram of an overview of an example implementation **100** described herein. In FIG. **1**, assume two network devices establish a multi-lane link to communicate data. For example, the multi-lane link may establish links (e.g., logical links) via multiple optical fibers or connections. Furthermore, assume each network device stores threshold bandwidth information indicating a threshold bandwidth that a bandwidth for the multi-lane link may not fall below.

Each network device may detect faulty lanes and communicate information regarding faulty lanes to the other network device, such that the faulty lanes determined by the network devices are synchronized. A faulty lane may be a lane with a particular error rate (e.g., greater than an error rate threshold), a particular power level (e.g., less than a power threshold), and/or a particular signal strength (e.g., less than a signal strength threshold). Each network device may determine an available bandwidth of the multi-lane link based on which lanes are still healthy (e.g., not faulty).

If the available bandwidth satisfies the threshold bandwidth (e.g., the available bandwidth is equal to or greater than the threshold bandwidth), the network devices may distribute the data among the healthy lanes to operate the multi-lane link at the available bandwidth (e.g., a reduced bandwidth). The data may not be distributed to the faulty lanes.

On the other hand, if the available bandwidth fails to satisfy the threshold bandwidth (e.g., the available bandwidth is less than the threshold bandwidth), the network devices may terminate the entire multi-lane link, even though there may still be healthy lanes.

In this way, the network device may allow a multi-lane link to operate at a reduced bandwidth when lanes become faulty without letting the reduced bandwidth fall below a threshold bandwidth.

FIG. **2** is a diagram of an example environment **200** in which systems and/or methods, described herein, may be implemented. As shown in FIG. **2**, environment **200** may include endpoint devices **210**, a network **220**, network devices **230**, a fiber **240**, and/or a manager device **250**. Devices of environment **200** may interconnect via wired connections, wireless connections, or a combination of wired and wireless connections.

Endpoint device **210** may include one or more devices capable of receiving and/or providing information over a network (e.g., network **220**), and/or capable of generating, storing, and/or processing information received and/or provided over the network. For example, endpoint device **210** may include a computing device, such as a laptop computer, a tablet computer, a handheld computer, a desktop computer, a super computer, a mobile phone (e.g., a smart phone, a radiotelephone, etc.), a personal digital assistant, a network device (e.g., a router, a gateway, a firewall, a hub, a bridge, etc.), a gaming device, or a similar device. Endpoint device **210** may act as an endpoint (e.g., a source and/or a destination) for a communication with another endpoint device **210**. For example, a first endpoint device **210** may provide information to a second endpoint device **210** (e.g., via network device **230** and/or network **220**).

Network **220** may include one or more wired and/or wireless networks. For example, network **220** may include a wireless local area network (WLAN), a local area network (LAN), a wide area network (WAN), a metropolitan area network (MAN), a telephone network (e.g., the Public Switched Telephone Network (PSTN)), a cellular network, a public land mobile network (PLMN), an ad hoc network, an intranet, the Internet, a fiber optic-based network, or a combination of these or other types of networks. In some implementations, network **220** may include a core network that uses multi-lane gigabit Ethernet technology (e.g., 400 gigabit (400G) Ethernet, 100 gigabit (100G) Ethernet, and/or 40 gigabit (40G) Ethernet). In some implementations, network **220** may allow communication between devices, such as endpoint devices **210**. Network **220** may include one or more network devices **230**, fibers **240**, and/or manager devices **250**.

Network device **230** may include one or more devices (e.g., one or more traffic transfer devices) capable of processing and/or transferring traffic between endpoint devices **210**. For example, network device **230** may include a firewall, a router, a gateway, a switch, a hub, a bridge, a reverse proxy, a server (e.g., a proxy server), a security device, an intrusion detection device, a load balancer, or a similar device. In some implementations, network device **230** may be included in a core network (e.g., a backbone network that provides paths for the exchange of information between sub-networks) of network **220**.

Fiber **240** may include a fiber or wire configured to transmit traffic or data between network devices **230** and/or endpoint devices **210**. For example, fiber **240** may include an optical fiber, comprising glass, plastic, and/or another material, used for fiber-optic communication. In some implementations, more than one fiber **240** may connect network devices **230** and/or endpoint devices **210** to allow communication between devices. In some implementations, multiple fibers **240** may be bundled to form a cord (not shown). For example, a 40G Ethernet cord may include at least eight fibers **240**, and a 100G Ethernet cord may include at least 20 fibers **240**.

Manager device **250** may include one or more devices capable of storing, processing, and/or routing information. For example, manager device **250** may include a computing device, such as a desktop computer, a laptop computer, a tablet computer, a server, or the like. In some implementations, manager device **250** may include a communication interface that allows manager device **250** to receive information from and/or transmit information to other devices in environment **200**. In some implementations, manager device **250** may manage one or more network devices **230** using a Simple Network Management Protocol (SNMP) and/or another protocol.

The number and arrangement of devices and networks shown in FIG. **2** is provided as an example. In practice, there may be additional devices and/or networks, fewer devices and/or networks, different devices and/or networks, or differently arranged devices and/or networks than those shown in FIG. **2**. Furthermore, two or more devices shown in FIG. **2** may be implemented within a single device, or a single device shown in FIG. **2** may be implemented as multiple, distributed devices. Additionally, or alternatively, a set of devices (e.g., one or more devices) of environment **200** may perform one or more functions described as being performed by another set of devices of environment **200**.

FIG. **3** is a diagram of example components of a device **300**. Device **300** may correspond to endpoint device **210**, network device **230**, and/or manager device **250**. In some implementations, endpoint device **210**, network device **230**, and/or manager device **250** may include one or more devices **300** and/or one or more components of device **300**. As shown in FIG. **3**, device **300** may include a bus **310**, a processor **320**, a memory **330**, a storage component **340**, an input component **350**, an output component **360**, and a communication interface **370**.

Bus **310** may include a component that permits communication among the components of device **300**. Processor **320** may include a processor (e.g., a central processing unit (CPU), a graphics processing unit (GPU), an accelerated processing unit (APU), etc.), a microprocessor, and/or any processing component (e.g., a field-programmable gate array (FPGA), an application-specific integrated circuit (ASIC), etc.) that interprets and/or executes instructions. Memory **330** may include a random access memory (RAM), a read only memory (ROM), and/or another type of dynamic or static storage device (e.g., a flash memory, a magnetic memory, an optical memory, etc.) that stores information and/or instructions for use by processor **320**.

Storage component **340** may store information and/or software related to the operation and use of device **300**. For example, storage component **340** may include a hard disk (e.g., a magnetic disk, an optical disk, a magneto-optic disk, a solid state disk, etc.), a compact disc (CD), a digital versatile disc (DVD), a floppy disk, a cartridge, a magnetic tape, and/or another type of computer-readable medium, along with a corresponding drive.

Input component **350** may include a component that permits device **300** to receive information, such as via user input (e.g., a touch screen display, a keyboard, a keypad, a mouse, a button, a switch, a microphone, etc.). Additionally, or alternatively, input component **350** may include a sensor for sensing information (e.g., a global positioning system (GPS) component, an accelerometer, a gyroscope, an actuator, etc.). Output component **360** may include a component that provides output information from device **300** (e.g., a display, a speaker, one or more light-emitting diodes (LEDs), etc.).

Communication interface **370** may include a transceiver-like component (e.g., a transceiver, a separate receiver and transmitter, etc.) that enables device **300** to communicate with other devices, such as via a wired connection, a wireless connection, or a combination of wired and wireless connections. Communication interface **370** may permit device **300** to receive information from another device and/or provide information to another device. For example, communication interface **370** may include an Ethernet interface, an optical interface, a coaxial interface, an infrared interface, a radio frequency (RF) interface, a universal serial bus (USB) interface, a Wi-Fi interface, a cellular network interface, or the like. Additionally, or alternatively, communication interface **370** may include a laser, a modulator, and/or another optical component to transmit data on a fiber **240**.

Device **300** may perform one or more processes described herein. Device **300** may perform these processes in response to processor **320** executing software instructions stored by a computer-readable medium, such as memory **330** and/or storage component **340**. A computer-readable medium is defined herein as a non-transitory memory device. A memory device includes memory space within a single physical storage device or memory space spread across multiple physical storage devices.

Software instructions may be read into memory **330** and/or storage component **340** from another computer-readable medium or from another device via communication interface **370**. When executed, software instructions stored in memory **330** and/or storage component **340** may cause processor **320** to perform one or more processes described herein. Additionally, or alternatively, hardwired circuitry may be used in place of or in combination with software instructions to perform one or more processes described herein. Thus, implementations described herein are not limited to any specific combination of hardware circuitry and software.

The number and arrangement of components shown in FIG. **3** is provided as an example. In practice, device **300** may include additional components, fewer components, different components, or differently arranged components than those shown in FIG. **3**. Additionally, or alternatively, a set of components (e.g., one or more components) of device **300** may perform one or more functions described as being performed by another set of components of device **300**.

FIG. **4** is a flow chart of an example process **400** for setting a threshold bandwidth. In some implementations, one or more process blocks of FIG. **4** may be performed by network device **230**. In some implementations, one or more process blocks of FIG. **4** may be performed by another device or a group of devices separate from or including network device **230**, such as endpoint device **210** and/or manager device **250**.

As shown in FIG. **4**, process **400** may include receiving threshold bandwidth information (block **410**). For example, network device **230** may receive the threshold bandwidth information from manager device **250**.

The threshold bandwidth information may be input into manager device **250** by a user responsible for managing network **220**. Manager device **250** may send the threshold bandwidth information to network device **230**. The threshold bandwidth information may indicate a threshold bandwidth, which may be a minimum permissible bandwidth for a multi-lane link. The threshold bandwidth may be user customizable.

A multi-lane link may include multiple virtual lanes that each operates at a particular bandwidth. Each lane may correspond to a fiber **240** or a pair of fibers **240** (e.g., one fiber **240** for transmitting data via a lane and another fiber **240** for receiving data via the lane). Data transmitted via multiple lanes may be aggregated to increase the total bandwidth with which the data is transmitted. For example, if X number of lanes included in a multi-lane link each has a bandwidth of Y, then the multi-lane link may have a total achievable bandwidth of X*Y. However, the total achievable bandwidth may not always be required and a lower threshold bandwidth may be permitted when one or more of the lanes is faulty, rather than terminating the entire multi-lane link when one or more lanes are faulty.

In some implementations, an internet service provider (ISP) may control network **220**. In such a case, the threshold bandwidth may be based on a committed bandwidth (e.g., a committed information rate (CIR)) that the ISP guarantees to maintain between different network devices **220**.

As further shown in FIG. **4**, process **400** may include setting a threshold bandwidth based on the threshold bandwidth information (block **420**). For example, network device **230** may set the threshold bandwidth by storing the threshold bandwidth information. In some implementations, the threshold bandwidth information may be updated and the threshold bandwidth may be changed based on new or updated threshold bandwidth information being received.

In case no threshold bandwidth information is received at block **410**, network device **230** may set the threshold bandwidth as the link bandwidth (e.g., the total achievable bandwidth of the multi-lane link) to maintain a legacy operation of the multi-lane link.

Although FIG. **4** shows example blocks of process **400**, in some implementations, process **400** may include additional blocks, fewer blocks, different blocks, or differently arranged blocks than those depicted in FIG. **4**. Additionally, or alternatively, two or more of the blocks of process **400** may be performed in parallel.

FIG. **5** is a flow chart of an example process **500** for automatically adjusting a bandwidth on a multi-lane link. In some implementations, one or more process blocks of FIG. **4** may be performed by network device **230**. In some implementations, one or more process blocks of FIG. **4** may be performed by another device or a group of devices separate from or including network device **230**, such as endpoint device **210** and/or manager device **250**.

As shown in FIG. **5**, process **500** may include establishing a multi-lane link with a peer device (block **510**). For example, network device **230** may establish the multi-lane link with the peer device. As used herein, the term "peer device" may refer to another network device **230**, endpoint device **210**, and/or any other device capable of communicating using a multi-lane link.

In some implementations, network device **230** and the peer device may be connected via multiple fibers **240** and use fibers **240** to establish the multi-lane link. Each lane of the multi-lane link may correspond to a fiber **240** or a pair of fibers **240** (e.g., one fiber **240** for transmitting data via a lane and another fiber **240** for receiving data via the lane).

As further shown in FIG. **5**, process **500** may include determining a fault state for each lane (block **520**). For example, network device **230** may detect the fault state for each lane.

A fault state may include a faulty state or a healthy state. A faulty state may indicate a lane is faulty and may not be used to communicate data. A healthy state may indicate a lane is healthy and may be used to communicate data. In some implementations, a lane may be faulty if one of and/or both fibers **240** in a lane is detected to be faulty.

In some implementations, network device **230** may detect whether a lane is faulty by measuring a power level of a fiber **240** used for the lane. If the power level satisfies a threshold power level, network device **230** may determine the lane is faulty. For example, if the measured power level of a fiber **240** is less than the threshold power level, network device **230** may determine the corresponding lane is in a faulty state. On the other hand, if the measured power level of fiber **240** is greater than or equal to the threshold power level, network device **230** may determine the corresponding lane is in a healthy state.

Additionally, or alternatively, network device **230** may detect whether a lane is faulty by measuring an error rate of data transmitted via the lane. If the measured error rate satisfies a threshold error rate, network device **230** may determine the lane is faulty. For example, if the measured error rate of the lane is greater than the threshold error rate, network device **230** may determine the lane is in a faulty state. On the other hand, if the measured error rate of the lane is less than or equal to the threshold error rate, network device **230** may determine the lane is in a healthy state.

In some implementations, network device **230** may detect whether a lane is faulty by measuring a signal strength of a signal used to communicate data via the lane. If the signal strength satisfies a threshold signal strength, network device **230** may determine the lane is faulty. For example, if the measured signal strength is less than the threshold signal strength, network device **230** may determine the corresponding lane is in a faulty state. On the other hand, if the measured signal strength is greater than or equal to the threshold signal strength, network device **230** may determine the corresponding lane is in a healthy state.

In some implementations, network device **230** may detect faulty optical components associated with a lane. If a faulty optical component is detected, a corresponding lane may be determined to be in a faulty state.

Network device **230** may store fault information, which indicates a fault state for each lane in the multi-lane link, in a memory included in or accessible by network device **230**. The fault information may indicate whether each lane is in a faulty state or a healthy state based on the fault state determined by network device **230**.

As further shown in FIG. **5**, process **500** may include sending a fault message to the peer device indicating the fault states of the lanes (block **530**). For example, network device **230** may send the fault message to the peer device.

In some implementations, the fault message may indicate the fault state of each lane. Additionally, or alternatively, the fault message may only indicate the fault states for lanes in a faulty state.

In some implementations, network device **230** may send the fault message at regular intervals. Additionally, or alternatively, network device **230** may send the fault message when a fault state of a lane changes.

In some implementations, network device **230** may send the fault message via the lanes. For example, network device **230** may send the fault message via a particular lane designated to communicate fault messages. Additionally, or alternatively, the fault message may be sent on a lane determined to be healthy. Network device **230** may wait for an acknowledgment from the peer device indicating the fault message was received. If the acknowledgment is not received in a particular amount of time, network device **230** may send the fault message to the peer device on a different lane, and repeat this process until an acknowledgment is received. In some implementations, if an acknowledgement is not received from the peer device (e.g., after sending the fault message on each lane or each healthy lane), then network device **230** may terminate the multi-lane link.

Additionally, or alternatively, network device **230** may send copies of the fault message via each lane to ensure the fault message reaches the peer device and is not transmitted over a faulty lane (e.g., an undetected faulty lane). Additionally, or alternatively, network device **230** may alternate which lane is used to send the fault message. For example, network device **230** may send a first fault message via a first lane, send a second, subsequent, fault message via a second lane, and so on.

In some implementations, network device **230** may transmit the fault message independent of the multi-lane link. For example, network device **230** may transmit the fault message wirelessly and/or via a fiber **240** not used for the multi-lane link.

The fault message may have a particular format that distinguishes the fault message from other data being transmitted via the multi-lane connection, such that the peer device may identify the fault message. The peer device may receive the fault message and update fault information, stored by the peer device, to indicate the fault states of the lanes.

In some implementations, if there is a discrepancy between the fault state for a lane detected by network device **230** and a fault state for the lane detected by the peer device, network device **230** may send a test message to the peer device via the lane to confirm the fault state of the lane. If the peer device receives the test message, returns a test response via the lane, and network device **230** receives the test response, then the lane may be determined to be in a healthy state. On the other hand, if network device **230** does not receive the test response, the lane may be determined to be in a faulty state.

As further shown in FIG. **5**, process **500** may include receiving a fault message indicating fault states of the lanes detected by the peer device (block **540**). For example, network device **230** may receive the fault message from the peer device.

The peer device may determine fault states of the lanes in the same way as described with respect to block **520**. The peer device may also send a fault message to network device **230** in the same way as described with respect to block **530**. Network device **230** may receive the fault message from the peer device. The received fault message may indicate fault states determined by the peer device for the lanes.

Network device **230** may update the fault information based on the received fault message. For example, network device **230** may update the fault information to indicate a lane is in a faulty state if either network device **230** or the peer device indicate the lane is faulty. On the other hand, network device **230** may update the fault information to indicate that a lane is in a healthy state if both network device **230** and the peer device indicate that the lane is healthy.

Similarly, the peer device may update fault information stored by the peer device based on the fault message sent by network device **230**. Accordingly, the peer device and network device **230** may be synchronized as to which lanes are determined to be faulty.

As further shown in FIG. **5**, process **500** may include determining an available bandwidth for the multi-lane link based on the fault states of the lanes (block **550**). For example, network device **230** may determine the available bandwidth based on the fault information.

In some implementations, network device **230** may calculate the available bandwidth based on the number of lanes in a healthy state and a bandwidth of each lane in the healthy state. For example, network device **230** may add the bandwidth of each lane in the healthy state together to determine the available bandwidth for the multi-lane link.

Network device **230** may store available bandwidth information, in a memory included in or accessible by network device **230**, indicating the available bandwidth for the multi-lane link.

As further shown in FIG. 5, process 500 may include determining whether the available bandwidth satisfies the threshold bandwidth (block 560). For example, network device may determine whether the available bandwidth satisfies the threshold bandwidth by comparing the available bandwidth, indicated by the available bandwidth information, and the threshold bandwidth, indicated by the threshold bandwidth information.

In some implementations, network device 230 may determine the available bandwidth satisfies the threshold bandwidth if the available bandwidth is greater than or equal to the threshold bandwidth. On the other hand, network device 230 may determine the available bandwidth does not satisfy the threshold bandwidth if the available bandwidth is less than the threshold bandwidth.

As further shown in FIG. 5, if the available bandwidth satisfies the threshold bandwidth (block 560—yes), process 500 may include transmitting and/or receiving data using the available bandwidth (block 570). For example, network device 230 may transmit and/or receive data using the healthy lanes. The data may be data being transmitted from a first end device 210 to a second end device 210 via network 220.

In some implementations, when transmitting data to the peer device, network device 230 may distribute the data to the healthy lanes (e.g., using a round-robin scheduling process and/or another scheduling process). Network device 230 may not distribute data to faulty lanes. The peer device may receive the data and combine the data.

In some implementations, when receiving data from the peer device, network device 230 may combine the data received on healthy lanes. If any data is received on faulty lanes, network device 230 may ignore the data received via faulty lanes.

As further shown in FIG. 5, if the available bandwidth does not satisfy the threshold bandwidth (block 560—no), process 500 may include terminating the entire multi-lane link (block 580). For example, network device 230 may terminate the multi-lane link by not communicating data via any of the lanes. Thus, even though there may be healthy lanes available that may be used to transmit the data at a reduced bandwidth, network device 230 may terminate the entire multi-lane link so as not to operate at the reduced bandwidth (e.g., a bandwidth less than a committed bandwidth).

As further shown in FIG. 5, process 500 may include providing a link state notification indicating a status of the multi-lane link (block 590). For example, network device 230 may provide the link state notification.

In some implementations, the link state notification may indicate whether the multi-lane link is active or terminated. Additionally, or alternatively, the link state notification may indicate the bandwidth of the multi-lane link. Additionally, or alternatively, the link state notification may indicate a lane and/or fiber 240 that is faulty.

In some implementations, network device 230 may provide the link state notification using a LED and/or a display device included in network device 230. For example, a LED may emit different colors to indicate whether the multi-lane link is active or terminated, and/or whether the multi-lane link is operating at a reduced bandwidth. Additionally, or alternatively, network device 230 may provide the link state notification by emitting a sound (e.g., an alarm). Accordingly, a person responsible for monitoring network device 230 may be able to determine a status of the multi-lane link based on the link state notification provided by network device 230.

In some implementations, network device 230 may provide the link state notification to manager device 250. For example, network device 230 may send the link state notification using a SNMP trap (e.g., an asynchronous notification from network device 230 to manager device 250). Additionally, or alternatively, network device 230 may provide the link state notification by indicating a change in a command-line interface (CLI).

Although FIG. 5 shows example blocks of process 500, in some implementations, process 500 may include additional blocks, fewer blocks, different blocks, or differently arranged blocks than those depicted in FIG. 5. Additionally, or alternatively, two or more of the blocks of process 500 may be performed in parallel.

FIGS. 6A-6C are diagrams of an example implementation 600 relating to example process 400 shown in FIG. 4 and example process 500 shown in FIG. 5. FIGS. 6A-6C show an example of setting a threshold bandwidth and automatically adjusting a bandwidth on a multi-lane link.

In FIG. 6A, assume a user inputs threshold bandwidth information into manager device 250. Further, assume the threshold information indicates a threshold bandwidth of 60 Gbit/s for a multi-lane link. Manager device 250 sends the threshold bandwidth information to network device 230 and network device 230 receives the threshold bandwidth information.

As shown in FIG. 6A, assume that network device 230 establishes a 100G multi-lane link with another network device 230 (e.g., a peer device). Also, assume that the 100G multi-lane link may use ten lanes that each has a bandwidth of 10 Gbit/s.

In FIG. 6B, assume network device 230 determines that two of the ten lanes are faulty. For example, network device 230 may detect that a signal strength for the two lanes (e.g., of a signal transmitted via fiber 240) is below a threshold value for a healthy lane. Network device 230 may send a fault message to the other network device 230 indicating that the two lanes are faulty and that the other eight lanes are healthy. The other network device 230 may receive the fault message and send network device 230 another fault message confirming that the other network device 230 also determined that the two lanes are faulty and the other lanes are healthy.

Thus, network device 230 may determine that the available bandwidth for the multi-lane link is 80 Gbit/s (e.g., 10 Gbit/s/lane*8 healthy lanes=80 Gbit/s). Network device 230 may determine that the available bandwidth (80 Gbit/s) is greater than the threshold bandwidth (60 Gbit/s). Accordingly, network device 230 may keep the multi-lane link active, with a reduced bandwidth of 80 Gbit/s, by distributing the data to the eight healthy lanes. Network device 230 may not distribute any data to the two faulty lanes.

As further shown in FIG. 6B, network device 230 may send a link state notification to manager device 250 (e.g., via a SNMP trap) indicating the multi-lane link is active and operating at 80 Gbit/s.

In FIG. 6C, assume network device 230 later determines that five of the ten lanes are faulty. For example, network device 230 may detect that a signal strength for the lanes (e.g., of a signal transmitted via fiber 240) is below a threshold value for a healthy lane. Network device 230 may send a fault message to the other network device 230 indicating that the five lanes are faulty and that the other five lanes are healthy. The other network device 230 may receive the fault message and send network device 230 another fault message confirming that the other network device 230 also determined that the five lanes are faulty and the other five lanes are healthy.

Thus, network device 230 may determine that the available bandwidth for the multi-lane link is 50 Gbit/s (e.g., 10 Gbit/s/lane*5 healthy lanes=50 Gbit/s). Network device 230 may determine that the available bandwidth (50 Gbit/s) is less than the threshold bandwidth (60 Gbit/s). Accordingly, network device **230** may terminate the entire multi-lane link so that the multi-lane link does not operate at a bandwidth less than the threshold bandwidth.

As further shown in FIG. **6**C, network device **230** may send a link state notification to manager device **250** (e.g., via a SNMP trap) indicating the multi-lane link has been terminated due to five lanes being faulty.

As indicated above, FIGS. **6**A-**6**C are provided merely as an example. Other examples are possible and may differ from what was described with regard to FIGS. **6**A-**6**C.

Implementations described herein may allow a multi-lane link to operate at a reduced bandwidth when lanes become faulty. However, in some implementations, the multi-lane link may be terminated if an available bandwidth fails to satisfy a threshold bandwidth, thus ensuring the multi-lane link operates at a satisfactory bandwidth. Furthermore, implementations described herein may provide a notification on the status of the multi-lane link to notify a user of the status of the multi-lane link.

The foregoing disclosure provides illustration and description, but is not intended to be exhaustive or to limit the implementations to the precise form disclosed. Modifications and variations are possible in light of the above disclosure or may be acquired from practice of the implementations.

As used herein, the term component is intended to be broadly construed as hardware, firmware, and/or a combination of hardware and software.

Some implementations are described herein in connection with thresholds. As used herein, satisfying a threshold may refer to a value being greater than the threshold, more than the threshold, higher than the threshold, greater than or equal to the threshold, less than the threshold, fewer than the threshold, lower than the threshold, less than or equal to the threshold, equal to the threshold, etc.

Certain user interfaces have been described herein and/or shown in the figures. A user interface may include a graphical user interface, a non-graphical user interface, a text-based user interface, etc. A user interface may provide information for display. In some implementations, a user may interact with the information, such as by providing input via an input component of a device that provides the user interface for display. In some implementations, a user interface may be configurable by a device and/or a user (e.g., a user may change the size of the user interface, information provided via the user interface, a position of information provided via the user interface, etc.). Additionally, or alternatively, a user interface may be pre-configured to a standard configuration, a specific configuration based on a type of device on which the user interface is displayed, and/or a set of configurations based on capabilities and/or specifications associated with a device on which the user interface is displayed.

It will be apparent that systems and/or methods, described herein, may be implemented in different forms of hardware, firmware, or a combination of hardware and software. The actual specialized control hardware or software code used to implement these systems and/or methods is not limiting of the implementations. Thus, the operation and behavior of the systems and/or methods were described herein without reference to specific software code—it being understood that software and hardware can be designed to implement the systems and/or methods based on the description herein.

Even though particular combinations of features are recited in the claims and/or disclosed in the specification, these combinations are not intended to limit the disclosure of possible implementations. In fact, many of these features may be combined in ways not specifically recited in the claims and/or disclosed in the specification. Although each dependent claim listed below may directly depend on only one claim, the disclosure of possible implementations includes each dependent claim in combination with every other claim in the claim set.

No element, act, or instruction used herein should be construed as critical or essential unless explicitly described as such. Also, as used herein, the articles "a" and "an" are intended to include one or more items, and may be used interchangeably with "one or more." Furthermore, as used herein, the term "set" is intended to include one or more items, and may be used interchangeably with "one or more." Where only one item is intended, the term "one" or similar language is used. Also, as used herein, the terms "has," "have," "having," or the like are intended to be open-ended terms. Further, the phrase "based on" is intended to mean "based, at least in part, on" unless explicitly stated otherwise.

What is claimed is:

1. A device, comprising:
one or more processors to:
store information indicating a threshold bandwidth with which a multi-lane link is permitted to operate;
establish the multi-lane link with a peer device,
the multi-lane link including a plurality of lanes used to communicate data with the peer device;
determine fault states for the plurality of lanes included in the multi-lane link,
a fault state, for a particular lane of the plurality of lanes, indicating that the particular lane is faulty,
the plurality of lanes including available lanes and faulty lanes;
determine an available bandwidth for the multi-lane link based on the fault states for the plurality of lanes;
terminate the multi-lane link when the available bandwidth fails to satisfy the threshold bandwidth; and
operate the multi-lane link, at the available bandwidth, when the available bandwidth satisfies the threshold bandwidth,
when operating the multi-lane link at the available bandwidth, the one or more processors are to:
communicate the data with the peer device via the available lanes of the plurality of lanes, based on a scheduling process and without adjusting a transmission rate of the data, and
prevent the data from being communicated with the peer device via the faulty lanes of the plurality of lanes.

2. The device of claim **1**, where the one or more processors are further to:
send a notification message to a manager device that manages the device,
the notification message indicating whether the multi-lane link is terminated or operating at the available bandwidth.

3. The device of claim **2**, where the one or more processors, when sending the notification message, are to:
provide the notification message using a Simple Network Management Protocol (SNMP) trap.

4. The device of claim **2**, where the notification message indicates the particular lane is faulty.

5. The device of claim **1**, where the one or more processors are further to:
receive the information indicating the threshold bandwidth from a manager device that manages the device.

6. The device of claim **1**, where the one or more processors are further to:
send a fault message to the peer device,
the fault message indicating the particular lane is faulty.

7. The device of claim 1, where the multi-lane link is established via a plurality of optical fibers.

8. A non-transitory computer-readable medium storing instructions, the instructions comprising: one or more instructions that, when executed by one or more processors of a device, cause the one or more processors to: establish a multi-lane link with a peer device, the multi-lane link including a plurality of lanes used to communicate data with the peer device; determine fault states for the plurality of lanes included in the multi-lane link, at least one of the fault states indicating a particular lane, of the plurality of lanes, is faulty, the plurality of lanes including available lanes and faulty lanes; determine an available bandwidth for the multi-lane link based on the fault states for the plurality of lanes; terminate the multi-lane link when the available bandwidth fails to satisfy a threshold bandwidth, the threshold bandwidth indicating a minimum bandwidth with which the multi-lane link is permitted to operate; and operate the multi-lane link, at the available bandwidth, when the available bandwidth satisfies the threshold bandwidth, when operating the multi-lane link at the available bandwidth, the one or more instructions cause the one or more processors are to: communicate the data with the peer device via the available lanes of the plurality of lanes, based on a scheduling process and without adjusting a transmission rate of the data, and prevent the data from being communicated with the peer device via the faulty lanes of the plurality of lanes.

9. The non-transitory computer-readable medium of claim 8, where the one or more instructions, when executed by the one or more processors, further cause the one or more processors to: receive a message from the peer device that indicates peer-determined fault states for the plurality of lanes as determined by the peer device, and where the one or more instructions, that cause the one or more processors to determine the available bandwidth for the multi-lane link, cause the one or more processors to: determine the available bandwidth based on the peer-determined fault states for the plurality of lanes.

10. The non-transitory computer-readable medium of claim 8, where the one or more instructions, that cause the one or more processors to establish the multi-lane link, cause the one or more processors to: establish the multi-lane link via a plurality of optical fibers.

11. The non-transitory computer-readable medium of claim 8, where the one or more instructions, when executed by the one or more processors, further cause the one or more processors to: send a fault message to the peer device, the fault message indicating the particular lane is faulty.

12. The non-transitory computer-readable medium of claim 11, where the one or more instructions, that cause the one or more processors to send the fault message to the peer device, cause the one or more processors to: send a copy of the fault message to the peer device on each of the available lanes of the plurality of lanes.

13. The non-transitory computer-readable medium of claim 11, where the one or more instructions, that cause the one or more processors to send the fault message to the peer device, cause the one or more processors to: send the fault message to the peer device on a first lane of the plurality of lanes; and send a subsequent fault message to the peer device on a second lane of the plurality of lanes, the second lane being separate from the first lane.

14. The non-transitory computer-readable medium of claim 8, where the one or more instructions, when executed by the one or more processors, further cause the one or more processors to: receive information indicating the threshold bandwidth from a manager device that manages the device.

15. A method, comprising:

establishing, by a device, a multi-lane link with a peer device,

the multi-lane link including a plurality of lanes used to communicate data with the peer device;

determining, by the device, fault states for the plurality of lanes included in the multi-lane link,

at least one of the fault states indicating a particular lane, of the plurality of lanes, is faulty,

the plurality of lanes including available lanes and faulty lanes;

determining, by the device, an available bandwidth for the multi-lane link based on the fault states for the plurality of lanes;

operating, by the device, the multi-lane link at the available bandwidth when the available bandwidth satisfies a threshold bandwidth,

the threshold bandwidth indicating a bandwidth with which the multi-lane link is permitted to operate,

operating the multi-lane link at the available bandwidth including:

communicating the data with the peer device via the available lanes of the plurality of lanes, based on a scheduling process and without adjusting a transmission rate of the data, and

preventing the data from being communicated with the peer device via the faulty lanes of the plurality of lanes; and

terminating, by the device, the multi-lane link when the available bandwidth fails to satisfy the threshold bandwidth.

16. The method of claim 15, where the device is a network device included in a core network, and

where the threshold bandwidth is based on a committed bandwidth between network devices included in the core network,

the network devices including the network device.

17. The method of claim 15, where determining the fault states comprises:

detecting power levels of fibers used to communicate the data with the peer device,

the fibers corresponding to the plurality of lanes; and

determining the fault states of the plurality of lanes based on the power levels of the fibers.

18. The method of claim 15, where determining the fault states comprises:

detecting error rates of the data communicated via the plurality of lanes; and

determining the fault states of the plurality of lanes based on the error rates.

19. The method of claim 15, where determining the available bandwidth comprises:

determining the available bandwidth based on a number of the available lanes and a lane bandwidth of each of the available lanes.

20. The method of claim 15, where the threshold bandwidth is less than a maximum possible bandwidth of the multi-lane link when each of the plurality of lanes is available.

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